ENERGY EFFICIENT CITIES INITIATIVE
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The Energy Efficient Cities initiative (EECi) is a cross-disciplinary research project at the University of Cambridge spanning the built environment, transport and urban land use. Its aim is to strengthen the UK’s capacity to address energy demand reduction and environmental impact in cities, by research in building and transport technologies, district power systems, urban planning, and urban design.


The need for improved energy efficiency at city scale is great. In the UK, buildings and ground transportation in urban areas – where 80% of the population currently lives – account for around two thirds of the country’s total energy demands.

But the challenges of energy efficiency in cities are complex. Cities are integrated systems composed of numerous components with interconnecting links. To solve these challenges, a systems-level approach is needed. Devising practical and realistic proposals for how cities can be reshaped can only be achieved through a holistic, cross-disciplinary approach.

The goal of the University of Cambridge Energy Efficiency in Cities initiative (EECi) has been to strengthen the UK’s capacity to address energy demand reduction in cities. The initiative has achieved this both through the systems-level approaches it has contributed and through the people it has trained and developed.

EECi researchers have developed a combined approach to buildings, transport and de-centralised power generation, which brings together design and technologies with the goal of energy demand reduction, and quantifies the impacts of specific technologies on energy use and emissions. In so doing, EECi has developed many early career researchers in the area of energy analysis; alumni have moved into both industrial and academic positions.

These achievements respond to key priority areas for achieving national policy objectives on energy demand reduction, carbon reduction and air quality. In 2011, EPSRC’s International Review of Energy identified capability-building priorities including the need for a ‘whole systems’ approach because of complex interaction between sectors; a focus on social behaviour; and an increased role for ICT in increasing operability, control and visibility. Such foci have been central to the EECi endeavour from its 2008 beginnings.

This publication is designed to show some of the ways EECi work is of practical benefit to decision-makers for our cities, whether policy-makers, planners, regulators or investors.

Professor Dame Ann Dowling
Head of Department, Department of Engineering, University of Cambridge
Introduction

EECi has developed robust new approaches that help practitioners and policy makers meet key challenges in energy efficiency. Its work on feasibility and implementation of energy-efficient technology within buildings, transport, and energy supply technologies in cities is distinctive in two important ways. First, EECi has extended current capabilities in probabilistic modelling for the first time to urban and national scales. Second, researchers have quantified uncertainties for energy use using state-of-the-art techniques, in the wider context of socio-economic, physical, and regulatory factors.

The initiative’s contribution in capacity-building for industry and academia has been substantial. 15 research associates, 19 PhD students and 15 Master’s students have been trained. EECi has benefitted greatly from the support of its 15 co-sponsors and 21 members of its industrial Stakeholder Network.

In selecting the EECi activities to illustrate here, we have had more than one focus. Outputs we judge most important – novel approaches that rely on physics-based modelling, often leading directly to new applications – are, of course, included. But we also wish to bring theoretical developments to life in their practical context. We therefore include case-study examples from work at all scales.

Many EECi activities interconnect: the whole is bigger than the sum of its parts. The culmination of EECi (and our starting point, opposite) is a combined analysis of buildings, transport and energy supply across the City of Westminster, London.

The City of Westminster simulation realises EECi’s ambition of enabling combined assessment of localised energy use, greenhouse gas emissions, and air pollution, helping decision-makers improve policy and planning for buildings, building clusters, transportation technologies and fuels, and district power generation in ways that reduce energy demand and impacts of energy use.

Adam Boies          Ruchi Choudhary          Ying Jin
EECi’s overarching goal has been to improve understanding of how energy services and technologies interact at the city scale.

One of the key questions faced by EECi researchers is whether an integrated approach to assessing buildings, transport, and energy supply could produce improved decision-making capability for clean, energy-efficient city planning.

Hence, in 2013, the EECi developed a new city-scale energy and emissions simulation tool to support energy policy and urban planning decisions. CiMo (City Model) is a high-resolution exploratory tool which offers a spatially differentiated, hourly physics model of energy demand, supply, emissions and air quality at the city scale.

The City of Westminster, within central London, was chosen for the first pilot application of CiMo due to its diversity of building types, transport services, and population. Westminster has a residential population of over 200,000 and a working population of over 600,000. Approximately 2.7 million road vehicles travel on its streets daily.

This project brings together the individual contributions of EECi researchers in the buildings, transport, and energy modelling fields. This has led to new insights into spatial distribution of energy consumption in cities, comparative costing of greenhouse emissions and air pollution within cities, and the identification of energy use and emissions ‘hotspots’.

High-resolution combined analysis of buildings and transport in districts: City of Westminster, London. The project is one of the first-known applications of bottom-up, integrated engineering modeling used to predict hourly energy use and emissions at the city scale.
Modelling energy consumption at city scale

The analysis of buildings in the City of Westminster capitalised on several recent developments: physical characteristics of individual buildings in the UK can now be inferred from new research literature and statistical data (e.g. EPC/DEC building performance certificate data since 2010), and three-dimensional geometries of individual buildings within Westminster are available from geographic databases. The result is that each individual building can be represented by a physical model.

EECi researchers used the University of Cambridge’s Darwin High Performance Computing cluster to undertake annual, hourly energy simulations of each of the 100,000 representational building models in the City of Westminster. CiMo enabled investigations of building retrofit and distributed energy generation viability to be performed spatially, respecting both the salient engineering and economic parameters that affect each building.

City of Westminster buildings analysis: view of annual building end-use heating demand by floor area. Baseline predictions have compared favourably with aggregate gas and electricity consumption data for small census areas.
Transport analysis is based upon an hourly model of the vehicle fleet travelling on the roads in Westminster and its composition by size, fuel, technology and speed. This enables a spatially-refined representation of technology and policy scenarios, now and in the future.

Analysis of traffic flows by vehicle type, time of day and location is possible by automatic traffic counters, sensors in and alongside roads, connected in-car satellite navigation systems and fleet vehicle tracking.

The researchers combined models of powertrains in conventional, hybridised and electric vehicles with temporal-spatial traffic patterns to determine the distribution of energy use and emissions, from the street level to full city scale.

City of Westminster transport analysis: view of annual fuel energy use by passenger vehicles per road segment. The base case results compare favourably with energy use and emissions at the borough scale.
Modelling energy consumption at city scale

The analysis of environmental impacts quantifies the effect of Westminster emissions sources on local air quality. The spatially resolved emissions from buildings and transport are processed in pollution dispersion models.

As a result it is possible to identify whether emissions in Westminster lead to exceedances of regulatory limits on air quality under present day and alternative technology and policy scenarios.

The relative contribution of buildings and transport to concentrations of regulated air pollutants are evaluated and mitigation strategies designed to address pollution hotspots can be recommended.

Annual average concentration of NO$_2$ due to Westminster emissions sources only (buildings + road vehicles). 40 µg/m$^3$ represents the limit value set out in the EU Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

Total annual CO$_2$ emissions from buildings and road vehicles per land area.

For more information on the City of Westminster pilot application, see www.eeci.cam.ac.uk.
Several EECi projects have produced outputs that can help planners, investors and developers make more informed decisions about the feasibility, design or configuration of distributed energy resource (DER) systems.

DER systems are small or medium-sized energy generators sited within energy distribution systems, located near the connected buildings they serve. In the UK, their growing use is assisted by government subsidies for low-carbon energy solutions that have high capital costs.

Feasibility studies need to focus not only on achieving return on investment. Other drivers influencing energy planning decisions – CO$_2$ emissions, local air quality and legislative targets – are also important, so that designs are pragmatic and meet decision-maker requirements.

EECi’s Distributed Energy Network Optimisation (DENO) model is designed to help minimise investment and operational costs of a distributed energy system. It can also be used to analyse trade-offs among the different technology and distribution options of a DER system against their economic and environmental impacts.

EECi research has informed distributed energy supply planning for the London 2012 Olympics legacy project: the Queen Elizabeth Olympic Park. Photo by Sludgegulper (CC BY-SA 2.0 licence).
Within DENO a group of energy generators and consumers are represented by a set of nodes and arcs. Nodes are the points where electricity, heating, and cooling are generated and/or consumed, while arcs represent the electricity, heating, and cooling distribution networks.

To optimise energy costs, DENO evaluates the consumer energy demands at each node at hourly intervals against the set of energy generation technologies capable of meeting the demand. DENO selects the optimal combination of technologies and their appropriate capacities, then determines the schedule for each unit that allows the energy system to meet the electricity, heating, and cooling demands of a group of consumers.

For sites with multiple consumer locations, DENO optimises the location of the generation units and the structure of the distribution network in order to minimise thermal losses.

Which distributed energy system is better for the environment?

A UK-US team of researchers from EECi and MIT has identified and monetised air quality and climate change impacts of currently installed combined heat and power (CHP) systems and those using ground source heat pumps (GSHP). Their study concluded that while GSHPs have a net environmental benefit, CHP systems have a net cost to the UK environment.

The spatial distributions of (a) PM$_{2.5}$, (b) nitrates and (c) organic aerosols, due to the emissions of CHPs, and (d) PM$_{2.5}$ due to boilers emissions alone.
Optimising the use of distributed energy

Ground source heat pumps: how cost-effective?

A post-occupancy evaluation of several significant GSHP installations in UK cities compared actual data with alternative configurations of GSHP use (hybrid and non-hybrid). EECi researchers used a novel approach for quantifying risks in the different scenarios modelled.

DENO has been used to analyse energy supply planning for future construction phases at the Queen Elizabeth Olympic Park (London 2012 legacy project). This 18-year development takes place against a backdrop of increasingly stringent carbon-reduction targets.

EECi’s Akomeno Omu and Ruchi Choudhary, with support from Alasdair Young, Buro Happold (project sponsor) examined possible solutions for achieving zero-carbon emission targets post 2016. Options are limited by constraints imposed by an existing on-site DER system. Analysis with DENO found that new buildings from 2016 can only be ‘zero carbon’ if biogas is used. If biogas proves infeasible for the site, developers will need to invest in off-site carbon reduction measures (‘allowable solutions’) in order to achieve target emissions reductions.

Although DENO was developed in a UK policy context (incorporating its legislative targets and incentive schemes), researchers are now tailoring the model, in collaboration with the Indian Institute of Information Technology, Hyderabad, to optimise energy supply systems for campus-scale developments in India.

Links

DENO was used to optimise options for building clusters in the City of Westminster project identified as candidates for the installation of CHP systems (pp.3–6).

DENO identified optimal energy systems serving buildings at the Royal Botanic Gardens, Kew (pp.15–18).

References, p.31: DENO, 9; Ground source heat pump evaluation, 6; Environmental impacts of DER, 10.
Energy analysis of buildings: urban scale

Adam Booth and Ruchi Choudhary have developed a ground-breaking model to help decision-makers assess retrofit options. It has enabled cost-benefit analyses of large, urban-scale, projects – from UK social housing stock to Japanese supermarkets.

Standard computer models for projecting energy savings of urban-scale building retrofits have two weaknesses. In a large property portfolio, the pattern of energy use will vary between different types of building; standard models don’t fully capture this effect. And they underplay uncertainties, such as the way that occupants’ behaviour may change as a result of retrofit. For example, if occupants can heat their rooms at lower cost than before, they may be tempted to turn the thermostat up.

For his PhD thesis, Adam Booth used Bayesian techniques – statistical methods for quantifying probability – to overcome these problems. He developed a Bayesian hierarchical framework which was then embodied in a new model: the Stochastic Urban Scale Domestic Energy Model, or SUSDEM.

Engels House, Salford, before and after retrofit. Detailed data was collected for SUSDEM on residents’ energy use. Source: City West Housing Trust, Manchester.
SUSDEM is a ‘bottom up’ tool that brings together detailed data, expert knowledge, and energy simulation. It begins by assessing energy efficiency potential in particular clusters of building, such as flats built in the 1960s/70s. From there, the tool scales up its projections to urban districts.

SUSDEM was developed to help City West Housing Trust evaluate the retrofit potential of their portfolio. The trust manages a large and diverse portfolio of social housing. Its 15,000 dwellings are spread across Salford, in Greater Manchester, UK.

The work with City West Housing Trust co-incided with the UK Government’s announcement of its ‘Green Deal’ scheme. Domestic energy users would be able to take out loans to fund retrofit measures such as double glazing, loft insulation, condensing boiler, wall insulation and draught proofing. The loans would be repaid via a charge added to future energy bills.

In the run-up to the scheme’s 2012 launch, the EECi researchers took the opportunity to investigate its potential value for the social housing sector. They used the Green Deal as a basis to evaluate the cost-effectiveness of standard retrofit measures on the City West Housing Trust stock.

The researchers clustered the trust’s buildings into sub-groups such as pre-1914 terraced homes or 1964–79 flats. Using Bayesian techniques the researchers quantified the effects, for each sub-group, of each of the retrofit measures available under the Green Deal. They included variables to account for uncertainties in installation costs, future prices of energy, and lifetime carbon savings.

The results of the study produced mixed news for the Green Deal. Its potential for social housing would be limited: historically, the sector has been quicker than private landlords to implement standard energy-efficiency measures, but higher-cost, higher-impact measures would require better subsidies. The results show though, that the monetary value of additional societal benefits – such as reduction in carbon emissions and improved thermal comfort is likely to more than outweigh the cost of any subsidies.
EECi researchers have developed a model using Bayesian techniques capable of quantifying uncertainties in the variation of energy consumption across buildings within a similar category. The work integrated very diverse information sources, such as mapping databases, floorspace statistics, and energy benchmarks. Analysis found that energy consumption across similar buildings in different districts varies more than would be expected. The calculations developed in this innovative model underpin a new open-source energy analysis tool designed for urban planners.

Spatial deviations from average gas consumption due to location of non-domestic buildings in London. These results were obtained by accounting for spatial proximity through Bayesian conditional autoregressive modeling.
The SUSDEM model has also attracted attention internationally. In Japan, for example, Dr Yohei Yamaguchi (Osaka University) has used the SUSDEM framework to analyse the supermarket sector in Hyogo prefecture.

In a new collaboration with EPCO Inc. – a smart metering company in Japan – SUSDEM will be extended to test demand-side energy management strategies for a set of solar powered homes in Tokyo.

Refrigeration cabinets are heavy energy consumers in supermarkets. Photo by David Pursehouse (CC BY 2.0 licence)

Links

SUSDEM is used in the City of Westminster project to parameterize the residential buildings (pp.3–6).

Retrofit decision-making for individual buildings and clusters (pp.15–18).

For further information on the Integrated Urban Building Energy Analysis tool for urban planners, see www.landecon.cam.ac.uk/research/lisa.

References, p.31: SUSDEM and the Green Deal, 2; Influence of district features on consumption, 5.
Often the least energy-efficient buildings are the hardest to retrofit cost-effectively. EECi’s bespoke models for simulating energy use in non-standard buildings have helped identify solutions.

Sometimes the problematic buildings are heritage properties. Others are contemporary buildings put to non-standard uses – for example, laboratories that use a lot of electrical equipment intermittently. In theory, existing simulation packages should be able to identify the most effective combination of retrofit measures. In practice, they often fall short: they are not easily configurable to represent the non-standard uses to which buildings may be put.

When such buildings form a portfolio owned by a single organisation, it pays to look at their energy needs as a group. It is then possible to evaluate trade-off between upgrading one building versus another, and to consider benefits offered by economies of scale.

One organisation with this type of portfolio is the Royal Botanic Gardens, Kew (London), an internationally renowned scientific research institution and major visitor attraction. Here, Rebecca Ward applied tools developed by EECi researchers in new ways, identifying options for reducing energy use and greenhouse gas emissions for Kew’s buildings.
Building-retrofit investment: tailored models

How can new models improve retrofit decision-making?

One new method used at Kew was DeBERA, or Decoupled Building Energy Retrofit Assessor, developed by Adam Rysanek. It ‘decouples’ the traditional building energy simulation process — where only a single model would predict building energy use — by using a sequence of smaller, tailor-made models instead. DeBERA (shown opposite) uses an innovative combination of building physics and economic modelling. Users can select any combination of retrofit measures and make 10-year financial forecasts under varying economic conditions, such as high or low energy prices. Decision-makers stand to benefit from the speed at which DeBERA investigates exhaustive numbers of scenarios. This markedly reduces the cost of identifying suitable ‘deep’ building retrofit options — those achieving energy-use reductions in the order of 50%.

To support top-level decision-making at Kew, Rebecca Ward started at the bottom, by analysing individual buildings. She used simulation models geared to each building’s main form of energy consumption — be it heating, or electricity for power equipment, appliances and lights.

The simulation of Kew’s glasshouses had to capture an unusual factor in buildings: transpiration heat flow — a vital process for plant life. No models existed that could simulate transpiration heat flow in glasshouses, so Rebecca developed a new, stand-alone one.

Jodrell Research Laboratory at the Royal Botanic Gardens, Kew.

Electricity Consumption (kWh)

- Herbarium
- Ruined Arch (MNG)
- Pavilion
- Lower Nurseries (B&M)
- Jodrell
- Orangery Place
- Cumberland Gate
DeBERA: a method for deep building retrofit decision-making using sequential models.

For analysing the Jodrell Research Laboratory, an EECi tool called the Demand Load Reconstructor had important benefits.

DELORES (Model I in the above figure) is a stochastic model for simulating how buildings are actually used. It generates hourly profiles of internal heat gains and electricity demand. This capability was important when analysing the laboratory’s use of lighting and appliances, since equipment is used there intensively at irregular intervals.
Rebecca found that major energy and cost savings could be made. For the glasshouses, measures to reduce air leakage would be the most effective ones consistent with the heritage nature of the structures. A potential 50% reduction of air leakage would reduce energy consumption by over 20%.

For the laboratory, Rebecca identified 15% energy savings from fume hoods and 5% from reduced use of lighting.

In further work at Kew, Rebecca also found a strong case for installing a distributed energy resource system between a group of buildings.

Rebecca’s innovative work simulating transpiration heat flow has led to further EECi work to develop a bespoke greenhouse simulation tool. This aims to meet the need for a product to optimise energy for growing food in urban greenhouses.

Links

The model used to investigate potential for a distributed energy resource system is DENO (pp.7–10)

For further information on the open-source tool DELORES see www.eeci.cam.ac.uk.

References, p.31: Royal Botanic Gardens, Kew case study, 12; DeBERA, 11.
Vehicles optimised for low greenhouse gas emissions can produce increased noxious emissions, while noxious abatement technologies can lead to reduced fuel efficiency – and hence increased greenhouse gas emissions.

Therefore policy makers must consider mitigation efforts aimed at reducing both noxious and greenhouse gas emissions. Meanwhile, transport companies and vehicle manufacturers must find affordable ways of complying with changing regulations.

EECi’s transport research quantifies impacts associated with transportation energy use, offering policy-makers and the transport sector insights to help with complex decisions.

Buses are an important form of public transport, but traditional diesel-engine vehicles emit both greenhouse gases and air pollution. Authorities across the world have increased their regulation of diesel emissions.

In London, TfL (Transport for London), the local government body that manages transport services, has introduced several hundred ‘hybrid’ buses with the aim of reducing carbon emissions. These buses combine an electric battery and diesel engine. The London bus fleet also contains many older vehicles with conventional diesel engines.
Breaches of air quality standards have raised concerns about health impact from vehicle emissions. This has led the Mayor of London’s office to introduce a ‘low emissions zone’, which requires that existing buses meet modern emissions standards within phased time limits.

TfL has considered various technologies for reducing noxious emissions. In this context, EECi researchers have developed a model to compare several drivetrain and exhaust after treatment technologies – both current and near-term-future options – examining their impact on noxious and greenhouse gas emissions. The model produces a cost-benefit analysis covering the business costs of implementing each scenario, the value of health impacts from air quality changes, and social impacts from climate change.

The results highlight how technologies that reduce noxious emissions may increase greenhouse gases. For example, a compressed natural gas lean burn engine was the best technology modelled for reducing particulate matter, but its greenhouse gas emissions were much higher than those from unconverted diesel buses, due to emissions of unburned methane.

Changes in London bus greenhouse gas emissions relative to the existing fleet (949 kTonne CO$_2$e per year) for differing bus fleet technology options. Diesel after treatment options include selective catalytic reduction and catalytic regenerating trap (SCRT), exhaust gas recirculation diesel (EGRD). Alternative drivetrain technologies include compressed natural gas lean burn (CNG) and electric hybrid buses.
Biofuels: how can uncertain effects be quantified?

Fuel blenders must use 5% renewable fuels from sustainable sources under the UK Government’s Renewable Transport Fuel Obligation (RFTO). The RFTO permits ethanol produced from wheat and other sources to count towards that requirement. However, EECi research showed that total carbon emissions associated with UK wheat ethanol can vary more than gasoline’s. This suggests that the RFTO’s greenhouse-gas intensity calculation for biofuels makes insufficient allowance for uncertainties like land use changes and nitrous oxide emissions from soil fertilizers.

Two diesel retrofit technologies reduced noxious emissions but slightly lowered vehicle efficiency, thereby increasing greenhouse gas emissions relative to the unconverted buses.

Adding all costs together – climate change, health, technology and operating costs – diesel retrofit was the least expensive, followed by electric hybrid buses, while the compressed natural gas option was the most costly.

The study shows that cross-impacts between different emissions must be recognised and planned for. This and other studies enable decision-making based on deeper understanding of costs and trade-offs.

![Graph showing total costs (3% Discount Rate)](image)

*Total additional costs associated with alternative London bus fleets. Costs include capital, operating, health impacts and climate change.*
An EECi study modelled the cost-effectiveness of light duty vehicle alternative powertrains and compared them with conventional engines to assess their likely appeal to car-buyers. Advanced conventional engines, e.g. down-sized, boosted, direct injection engines, could deliver up to half the energy-use reductions of more costly alternative drivetrains. Only conventional cars with advanced engines and a few hybrid electric ones are likely to appeal to consumers: these promise fuel savings that offset the higher purchase price within two years.

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### Links

City of Westminster project: surface transport energy and greenhouse gas emissions model (pp.3–6).

Measuring emissions from air and rail transport (pp.23–26).

References, p. 31: Bus study, 4; Biofuels, 13; Alternative powertrains, 1.
Better information for reducing air pollution

A recent review by the independent Airports Commission concluded that an additional runway will be needed in south east England by 2030. As a result, airport emissions are again high on the UK political agenda.

EECi researchers have evaluated the air quality impacts of airport operations in the present day and under future expansion scenarios. Their work shows that policy and practice can be better informed to reduce the public health impacts of increased air traffic.

For baseline data the Cambridge and MIT team of researchers created a simulation of pollutant concentrations due to UK airport emissions in the present day (illustrated below).

Annual average ground-level $PM_{2.5}$ concentration due to the emissions from the 20 major UK airports in 2005: (a) total $PM_{2.5}$ and (b) black carbon (soot) only. Emissions at London Heathrow are higher than elsewhere due to volume of air traffic.
They employed newly-developed aircraft emissions models to populate atmospheric chemistry and transport models in order to estimate concentrations of pollutants over the UK attributable to airport activity. Public health impacts were estimated using the latest epidemiological evidence, which indicates an increased health risk due to higher concentrations of fine particles (PM$_{2.5}$).

The analysis included emissions from aircraft take-off and landing, aircraft auxiliary power units (APUs), and ground support equipment.

One finding was that airport emissions on their own do not lead to pollutant concentrations in their vicinity that are higher than regulatory air quality limits.

Nevertheless, the research estimated that ~110 early deaths occur in the UK each year as a result of airport emissions and a third of these are within 20 miles (32 km) of London Heathrow.

The researchers evaluated various strategies for reducing emissions – desulphurising jet fuel, electrifying ground support equipment, avoiding the use of APUs and reducing the number of engines used for taxiing to and from the runway.

They estimated that using all these strategies would enable UK airports to decrease noxious emissions significantly – with potential reductions of ~20% for nitrogen oxides to ~45% for particulate mass.

Photo by Angelo De Santis (CC BY 2.0 licence)
The models were then used to estimate 2030 airport emissions using different air traffic forecasts from the Department for Transport. Four scenarios involving expansion of airport capacity – shown in the following table – were compared with a scenario without expansion.

Even with no new runways in the UK, the number of annual early deaths is estimated to increase to ~250 in 2030 as a result of increasing air traffic and emissions at airports that have spare slots, an increasing and ageing population, and a changing atmosphere. However, these impacts could be offset by concerted action to reduce emissions using the strategies outlined.

In the expansion scenarios: if a third runway is added at Heathrow, the specific health impacts of the UK’s hub airport would rise, but UK-wide impacts on public health could be mitigated by emission-reduction strategies implemented across all airports.

From a health perspective, relocating the UK’s main hub airport to the Thames Estuary is beneficial. In this scenario, UK-wide early deaths are reduced by a quarter and the impact of the hub by 60–70%. A scenario implementing this policy along with all of the emission-reduction strategies keeps the public health impacts of airports at today’s level for a 50% increase in air passengers.

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<th>2030 expansion scenario</th>
<th>Number of early deaths relative to ‘no expansion’ scenario</th>
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<tr>
<td>Expansion of London Heathrow (3rd runway)</td>
<td>+11 (+8 to +20)</td>
</tr>
<tr>
<td>Replacement of Heathrow by a new Thames Estuary airport</td>
<td>-60 (-44 to -94)</td>
</tr>
<tr>
<td>Expansion of London Heathrow + all mitigation measures UK-wide</td>
<td>-110 (-81 to -170)</td>
</tr>
<tr>
<td>A new Thames Estuary airport + all mitigation measures UK-wide</td>
<td>-140 (-110 to -230)</td>
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Estimates for changes in the number of early deaths per year in the UK due to airport emissions in 2030, including 90% confidence intervals. Confidence intervals are shown in parentheses.
Better information for reducing air pollution

**Do diesel train emissions contribute to unhealthy air in UK train stations?**

Another EECi study measured air quality in London’s Paddington station and calculated benefits from retrofitting engines with diesel particulate filters. Paddington station has the third largest fleet of diesel trains in the UK, serving the country’s longest non-electrified train line. The diesel-powered trains have not been adapted to reduce emissions of particles and nitrogen oxide. The research found that the enclosed station area may pose health risks to workers and passengers, as nitrogen oxide concentrations exceed EU limits.

**Links**

Simulation techniques used in the airport study were also used in the City of Westminster project (pp.3–6).

Reducing emissions from road vehicles (pp.19–22)

References p.31: UK airports, 14; London Paddington trains, 3.
Influencing behaviour: transport and street-life

Behaviour change is critical to achieving reduction in energy demand. EECi has used its urban modelling expertise to enhance understanding of people on the move in cities. Its contributions include new ways of modelling travel patterns as well as studies focused on problems of individual cities – from the UK to China.

The street patterns of the Old City in central Beijing remained largely unchanged for seven centuries. Recently, however, there has been widespread change. Many areas have been redeveloped: modern road blocks have replaced traditional streets and alley ways in order to accommodate motor transport.

The old city area now has a dual structure. On the one hand, there are conservation areas, characterised by the preservation of east-west alleys (‘hutong’) and traditional neighbourhood layout. On the other hand there are redeveloped zones, characterised by a grid pattern of roads and largely mono-functional blocks.

Overall, there has been a marked decline in pedestrian liveliness, with a fall in pedestrian movements and socialising outdoors. By 2010, only 13% of all the trips of those who owned cars were made on foot, and the corresponding percentage for those who did not have cars was 24%. This contrasted strikingly with the proportion of walking trips, accounting for 36% of all trips in the city, in the late 1980s. Similarly, those who cycled in 2010 accounted for 16% of all trips, a reduction from 63% in 1986.
There are now efforts to regain pedestrian liveliness in the Old City. As a part of this initiative, in 2012 Ye Zhang, Ying Jin, and Koen Steemers investigated the effects of street geometry and land use distribution on pedestrian activities, focusing on an area of 3.8 sq. kilometres that comprise both the traditional neighbourhoods and redeveloped zones.

Their study applied five models for predicting pedestrian behaviour. The models focus on various indices (‘closeness centrality’, ‘spatial integration’, ‘accessibility’, and ‘place syntax’) and on the effects of urban design upon the pedestrian environment. These models, which have previously been used separately, were here used jointly for the first time. Hourly sampled observations were conducted and the resulting patterns compared with predictions generated from the models. This has led to the development of a new tool for urban designers and architects to test their design concepts and monitor progress in a rigorous manner.

The results revealed that the design of the street-alleyway environment has an overwhelming impact on the distribution of pedestrian movements, though a moderate one on stationary activities such as outdoor socialising. There was a marked difference between patterns of activity observed in the historic conservation areas and those in the redeveloped areas.

Through the comparisons the researchers were able to identify the key factors associated with pedestrian activities. In particular, they suggested ways to stimulate pedestrian activity, especially through a new type of organic renewal incorporating road alignment design at a level of detail that has not been considered in most cities. This enables urban planners and designers to implement radical change in redeveloped areas through small incremental steps, which is an emerging strategy to retrofit our cities for energy efficiency in travel.
Adaptive modification of streets and alleyways in the Old City of Beijing and their forecast effects on pedestrians: a. Existing alleyway network with a superimposed alignment of the proposed new alleyway (in purple); b. Forecast intensity of pedestrian activity in the existing alleyway network without the new alleyway; c. Planned alleyway network incorporating the new alleyway; d. Forecast intensity of pedestrian activity incorporating the new alleyway. The colours in (b) and (d) indicate the intensity of pedestrian activity in dark blue (weakest), rising to light blue, green, yellow and red (strongest).
Influencing behaviour: transport and street-life

How do people make travel choices?

Understanding how people make travel choices is essential for designing effective transport energy policy. But travel behaviour is complex, with a multitude of different influences that interact among themselves. An innovative EECi approach, based on structural equation modelling, investigates the combined influences of socio-economic profiles, demographics, urban land use, transport accessibility and car ownership. It looks at the time spent in travel, as well as the distance travelled. Travel choices and transport energy demand stem from both travel time and travel distance, although the existing literature has only focused on the implications of travel distances.

EECi has investigated various ways to improve tools available to urban modellers – such as spatial interaction techniques used to model travel patterns. Traditional models use discrete, equal-sized zones to represent locations. For computationally-heavy analyses, this forces modellers to compromise on spatial resolution and coverage as well as on rigour and depth of analysis. In contrast EECi’s new method – adaptive zoning – proposes that the appropriate size of destination zones depends on the distance to their origin zone: at short distances, spatial accuracy is important and destination zones must be small; at longer distances, knowing the precise location becomes less important and zones can be larger. The new method defines a specific zone map for every origin zone; each origin zone becomes the focus of its own map, surrounded by small zones nearby and large zones farther away. In tests, the adaptive zoning model reduced the computational load by 90% while containing about twice the information of a traditional method, for modelling the origin-destination patterns of travel and for the choice of the means of travel.

These new techniques have enabled the EECi urban modelling team to establish an overarching recursive spatial equilibrium model to test and monitor urban energy efficiency initiatives from the city region scale down to individual sites, such as the surrounds of rail and metro stations.

Links

Building energy analysis models at urban scale (pp.11–14).

References, p.31: Beijing study, 15; How people make travel choices, 7: Spatial interaction techniques, 8.
References


For a complete list of EECi publications and presentations, see www.eeci.cam.ac.uk.
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